

SEASONAL NUTRIENT CYCLING IN *POTAMOGETON PECTINATUS* OF THE LOWER PROVO RIVER

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ABSTRACT.—A common submersed aquatic plant of Great Basin wetland and riverine systems, *Potamogeton pectinatus* L. (sago pondweed) is a key waterfowl food. Nutritional qualities of submersed aquatics in the Great Basin are little understood. The purpose of this study was to determine the seasonal element cycling and nutritional qualities of *P. pectinatus* drupelet, leaf, and root tissues from the lower Provo River. Leaf tissue protein was 27% (dry weight) in July, but declined to 15% by December. Drupelet protein content was 9% in July and 6.5% in October. Lignocellulose in leaf tissue was lowest in July at 34% and increased as the season progressed. Percent fat was highest in leaf tissue at 12% in July. Sugars were highest in *P. pectinatus* leaf tissues in December and July. Calcium and magnesium concentrations increased in *P. pectinatus* tissues over the entire season. Leaf tissue zinc was 329 ppm (dry weight) in October. Leaf iron concentration was highest in September at 1184 ppm, while root tissue iron was 7166 ppm. Manganese content in leaf tissue peaked in October at 4990 ppm. Copper concentrations in leaves and roots were variable. High protein in leaf tissue would benefit local nesting and brooding waterfowl populations that feed on this aquatic. Trace metal concentrations in leaf and root tissues, from possible anthropogenic activities, appear very high during fall migratory months. Metal bioaccumulation by this species in other Great Basin wetlands and possible metal toxicity in waterfowl warrant further study.

Key words: sago pondweed, *Potamogeton pectinatus*, nutritional qualities, trace element cycling, metal bioaccumulation, waterfowl.

A common submersed aquatic plant of the Great Basin, *Potamogeton pectinatus* is a key primary producer in fresh and saline wetlands (Kantrud 1990). Waterfowl feed on all plant parts including drupelet, leaf, and root tissues (Anderson and Ohmart 1988, Korschgen et al. 1988). Sherwood (1960) noted that whistling swans (*Olor columbianus*) fed heavily on tubers and drupelets during fall migration in the Bear River Migratory Bird Refuge and Ogden Bay Refuge. Other waterfowl species—Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), pintails (*Anas acuta*), gadwalls (*Anas strepera*), canvasbacks (*Aythya vallisneria*), and redheads (*Aythya americana*)—also fed on *P. pectinatus* leaf and root tissues. Localized intermountain trumpeter swan (*Cygnus buccinator*) populations are also largely dependent on submersed aquatic plants as food (Anderson et al. 1986, Henson and Cooper 1993).

Little is known concerning nutrient dynamics and seasonal element cycling of *P. pectinatus* from Great Basin wetlands (Kadlec and Smith 1989). Consequently, how this aquatic species may affect waterfowl nutrition is poorly understood. Most assumptions concerning body

condition and nutritional requirements are based on studies from other areas of North America. Yet, energy and sustenance required by waterfowl species that frequent the Great Basin are largely provided by resident aquatic plants. Of these, *P. pectinatus*, *Ruppia maritima* L. (widgeon grass), *Scirpus maritimus* L. (alkali bulrush), *Scirpus pungens* L. (Olney three-square), *Scirpus acutus* L. (hardstem bulrush), and *Zammichellia palustris* L. (horned pondweed) are common plant species managed in national refuges and waterfowl management areas. *Potamogeton pectinatus* is considered the most important of these species for diving and dabbling ducks (Kadlec and Smith 1989). The purpose of this study was to determine the seasonal element concentrations and nutritional qualities of *P. pectinatus* from a local Great Basin river drainage.

METHODS

Plant harvests were conducted monthly from three locations within the lower Provo River drainage from July 1991 to December 1991: (1) just below Deer Creek dam (40°24'N,

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TABLE 1. A range of measured water column and sediment characteristics, pH, and electrical conductivity (EC) from the lower Provo River drainage.

	Water	Sediment
Clarity	clear-opaque	...
Velocity (m/sec)	0-0.4	...
Depth (cm)	5-60	>120
Temperature (°C)	3-14	3-12
pH	7.4	6.9
EC ($\mu\text{mhos}/\text{cm}^3$)	425	1570

111°31'W, elev. 1603 m), (2) near the Sundance turnout (40° 22'N, 111°34'W, elev. 1560 m), (3) ≈200 m from the mouth of the Provo River near Utah Lake (40°14'N, 111°44'W, elev. 1347 m). Water column and sediment characteristics measured in the lower Provo River are found in Table 1. Sediment conditions ranged from stony with gravelly patches to silty-clay mud. Stands of *P. pectinatus* were most abundant on muddy sediments.

Whole plants (leaf and root tissues) of *P. pectinatus* were sampled in replicate from each location. Drupelets, shoot (stems and leaves) tissues, and belowground (root, rhizomes, and turions) tissues were separated from plant litter and sediments. Invertebrates were removed from samples when rinsed in warm water (38°C). Cleaned samples were rinsed in deionized water and dried in a forced-air oven at 70°C. Plant, sediment, and water samples were analyzed at Brigham Young University, Department of Agronomy and Horticulture, Plant and Soil Analysis Laboratory. Dry plant tissue samples were weighed and ground in a Wiley Mill to pass a 40-mesh screen, and 0.25-g samples were digested in Folin-Wu tubes with 5 ml of concentrated HNO₃. Samples were left covered for 16 h before digestion in an aluminum block for 1 h at 100°C. Three ml of 70% HClO₄ was added, and samples were refluxed at 200°C until the solution cleared (approx. 30 min). Samples were then brought to 50-ml volume with deionized water (Orson et al. 1992). Element contents were detected by direct aspiration into a Perkin-Elmer Model 5000 Atomic Absorption Spectrophotometer. All blanks and standards were run with the same procedures. Percent total nitrogen and phosphorus were determined using a Kjeldahl digestion followed by analysis with an ALP-KEM rapid-flow analyzer.

Sediment (0-30 cm) and water (1000 ml) samples were obtained from the same loca-

TABLE 2. Mean exchangeable Fe and Mn from lower Provo River drainage sediments (ppm dry weight ± S.E., $n > 3$). Means sharing the same letter are not significantly different ($P \leq .05$).

Depth (cm)	Fe	Mn
0-7	61.6 ± 0.7a	19.2 ± 1.2a
7-15	56.5 ± 1.4a	11.4 ± 0.8b
15-22	61.3 ± 1.7a	9.4 ± 2.1b
22-30	57.1 ± 0.8a	12.0 ± 1.7b

tions and intervals as plant samples. Sediments were air-dried and extracted for exchangeable iron (Fe) and manganese (Mn) with diethylenetriaminepenta-acetic acid (DTPA) and detected by atomic absorption spectroscopy. Water samples were analyzed for pH, electrical conductivity ($\mu\text{mhos}/\text{cm}^3$), and available Fe and Mn with an Orion Micro-processor Ion-analyzer/901 pH meter, a wheat-stone bridge, and by atomic absorption spectroscopy.

Mean concentrations and standard errors (S.E.) were determined for each plant, sediment, and water sample. To determine if significant variation in plant tissue nutrient and element concentrations existed between the different months, we used analysis of variance (ANOVA) where month was considered the fixed effect and sample site the experimental unit in a repeated measures design. If significance ($P \leq .05$) was found, Tukey's multiple comparison procedures were used to separate means.

RESULTS AND DISCUSSION

Available Fe and Mn concentrations in water samples were 0.06 ± 0.01 and 0.001 ppm. Sediment exchangeable Fe and Mn contents were found between the normal soil range of 5-65 ppm. Yet, under anoxic conditions that are common in sediments, Fe and Mn may become more available for root uptake (Spencer and Brewer 1971, Tisdale et al. 1985; Table 2). Significant differences in sediment exchangeable Mn were found between surface sediments (0-7 cm) and the rest of the sampled profile (Table 2).

Element concentrations and forage qualities were determined for *P. pectinatus* tissues from July to December. Leaf and root tissue dry matter, as a percentage of fresh weight, remained constant at 6-7%, with the highest

dry matter content observed in October. Throughout the season, *P. pectinatus* element and forage composition varied with growth stage. Significant variation in leaf tissue protein was found ($F = 21.69$; d.f. = 4,14; $P < .001$) between July, September, October, and December (Table 3). Drupelet protein content was higher in July than in October. In all months sampled, leaf tissue protein was higher than drupelet protein. Percent protein in leaf tissue was higher than values reported in other studies (Linn et al. 1975, Kantrud 1990). Acid detergent fiber (ADF) analysis revealed that leaf tissue was lowest in lignocellulose (fiber) in July, but significant differences ($F = 3.03$; d.f. = 4,14; $P = .07$) in fiber content were not observed as the year progressed. Linn et al. (1975) found *P. pectinatus* leaf fiber content of 33% that is similar to values observed in this study. Increased fiber content would decrease the overall forage quality of leaf tissue. Significant variation did exist ($F = 177.40$; d.f. = 4,14; $P < .001$) in leaf tissue fat content and was highest in July. Total non-structural carbohydrates (sugars) in leaf tissues were highest in December and differed from all other months ($F = 42.19$; d.f. = 4,14; $P < .001$). By October, drupelet fat and sugar content were both higher than values found in July.

Percent nitrogen (N) and phosphorus (P) in leaf tissue reached peak concentrations in July but were significantly lower by December ($F = 23.37$; d.f. = 4,14; $P < .001$) ($F = 79.30$; d.f. = 4,14; $P < .001$; Table 4). Vermaak et al. (1983) stated that *P. pectinatus* played an important role in P cycling in aquatic systems. Cultured *P. pectinatus* grown in water relatively high in phosphate ($\text{PO}_4\text{-P}$) (0.3 ppm) bioaccumulated P^{32} to 4738 times the amount found in the water column. Nitrogen and P content in *P. pectinatus* can be well above that required for plant growth; this would indicate luxury consumption of these elements (Jupp and Spencer 1977, Ho 1979, Madsen 1986). Significant concentrations of calcium (Ca) and magnesium (Mg) accumulated ($F = 29.12$; d.f. = 4,14; $P < .001$) ($F = 278.71$; d.f. = 4,14; $P < .001$) in leaf tissue between July and December. This may indicate abiotic deposition, though no visible encrustation on exterior leaf or stem surfaces was observed. Hutchinson (1975) reported that *P. pectinatus* leaves were higher in Ca, Fe, K, Mg, Na, and several micronutrients than other aquatic plants. Yet, no mention of time sampled was given for these mineral concentrations. Therefore, no knowledge of seasonal accumulation was determined. Potassium (K) content was highest in September and differed significantly from percent K content in July (F

TABLE 3. Mean protein, fiber, fat, and sugar content in *P. pectinatus* drupelet and leaf tissue over five months. Forage quality constituents expressed as % dry weight \pm S.E., $n > 3$. Means sharing the same letter are not significantly different ($P \leq .05$).

Month	Tissue	Protein	ADF ^a	Fat	TNC ^b
----- (% dry wt.) -----					
July	Leaf	27.4 \pm 0.3a	34.2 \pm 0.9a	12.2 \pm 0.1a	8.3 \pm 0.1a
Aug.	Leaf	24.9 \pm 0.3ab	35.6 \pm 2.8a	6.5 \pm 0.2b	8.1 \pm 0.4a
Sept.	Leaf	21.4 \pm 0.3b	39.7 \pm 0.4a	6.8 \pm 0.2b	7.9 \pm 0.2a
Oct.	Leaf	20.3 \pm 1.4b	37.9 \pm 1.3a	7.1 \pm 1.1b	8.6 \pm 0.1a
Dec.	Leaf	15.1 \pm 0.3c	38.1 \pm 0.5a	5.9 \pm 1.1c	11.0 \pm 0.1b
July	Drupelet	9.0 \pm 0.5	33.4 \pm 0.6	6.1 \pm 0.7	12.0 \pm 0.3
Oct.	Drupelet	6.5 \pm 0.8	36.3 \pm 1.3	7.4 \pm 0.8	16.3 \pm 1.2

^aAcid detergent fiber (ADF), a measure of percent lignocellulose or fiber

^bTotal nonstructural carbohydrate (TNC), a measure of sugars

TABLE 4. Mean mineral element concentration in *P. pectinatus* leaf tissue over five months. Element content expressed as % dry weight \pm S.E., $n > 3$. Means sharing the same letter are not significantly different ($P \leq .05$).

Month	Tissue	N	P	K	Ca	Mg	S
----- (% dry wt.) -----							
July	Leaf	4.4 \pm 0.7a	0.6 \pm 0.1a	1.9 \pm 0.2a	1.3 \pm 0.1a	0.3 \pm 0.04a	1.2 \pm 0.1a
Aug.	Leaf	2.8 \pm 1.0a	0.5 \pm 0.1a	3.5 \pm 0.1b	1.2 \pm 0.1a	0.5 \pm 0.01b	
Sept.	Leaf	3.4 \pm 0.1a	0.5 \pm 0.2a	3.7 \pm 0.1b	1.4 \pm 0.04ab	0.6 \pm 0.02c	1.8 \pm 0.2b
Oct.	Leaf	3.3 \pm 0.2a	0.5 \pm 0.1a	3.1 \pm 0.1b	1.7 \pm 0.1b	0.6 \pm 0.01c	
Dec.	Leaf	2.4 \pm 0.1b	0.2 \pm 0.1b	3.0 \pm 0.3b	2.3 \pm 0.1c	0.7 \pm 0.02c	0.6 \pm 0.1c

TABLE 5. Mean trace element concentration in *P. pectinatus* leaf tissue over five months. Element content expressed as ppm dry weight \pm S.E., $n > 3$. Means sharing the same letter are not significantly different ($P \leq .05$).

Month	Tissue	Zn	Fe	Mn	Cu
----- (ppm dry wt.) -----					
July	Leaf	213 \pm 14a	633 \pm 67a	122 \pm 6a	21 \pm 4a
Aug.	Leaf	185 \pm 10a	1097 \pm 58b	1744 \pm 101b	10 \pm 1b
Sept.	Leaf	211 \pm 1a	1184 \pm 75b	3861 \pm 117c	10 \pm 1b
Oct.	Leaf	329 \pm 4b	963 \pm 73b	4990 \pm 48d	11 \pm 0b
Dec.	Leaf	295 \pm 13b	1038 \pm 63b	2130 \pm 65b	8 \pm 0b

= 26.40; d.f. = 4,14; $P < .001$). Percent sulfur decreased between July and December ($F = 13.41$; d.f. = 2,10; $P = .03$; Table 4).

Zinc (Zn) concentration in leaf tissue was significantly higher ($F = 36.56$; d.f. = 4,14; $P < .001$) in October and December than in all other months (Table 5). Mean Fe content was higher in August leaf tissue than in July ($F = 12.59$; d.f. = 4,14; $P = .001$), after which Fe content remained fairly constant throughout the remainder of the sample period. Leaf tissue Mn content increased through the season and was highest in October ($F = 587.38$; d.f. = 4,14; $P < .001$; Table 5). Dudkin et al. (1976) found that *P. pectinatus*, growing in polluted coastal waters of the Black Sea, accumulated Mn to 0.5% (dry weight). This Mn concentration corresponds to values found in this study. Yet, Mn concentrations in water and sediment from the lower Provo River appear normal. Copper (Cu) in leaf tissue varied significantly ($F = 44.48$; d.f. = 4,14; $P < .001$), with high concentrations in July followed by lows in August through December (Table 5).

Root tissues (root, rhizomes, and turions) of *P. pectinatus* were not separated for analysis. Mean root tissue forage qualities, compared to leaf tissues, were lower in percent protein but higher in fat content (Table 6). Phosphorus was the only mineral element with a concentration higher in root tissues than in leaf tissues. Mineral (N, P, K, Ca, and Mg) contents of root tissues in this study were similar to contents found in other studies (Kollman and Wali 1976, Van Vierssen 1982). High trace metal concentrations were also found in root tissues. Like leaf tissues, mean Fe and Mn concentrations in root tissues appear inordinately high.

CONCLUSIONS AND FUTURE RESEARCH

Seasonal variation did exist in forage qualities and nutrient concentrations in *P. pectinatus*. Protein content in leaf tissue was highest

in the summer months when *P. pectinatus* was growing rapidly. By fall and early winter, protein content decreased but was still higher than concentrations found in drupelets. Apparently, protein content in *P. pectinatus* leaf tissue from the lower Provo River was higher than concentrations reported elsewhere. High protein content in leaves and stems in the summer months would greatly benefit nesting and brooding waterfowl that feed on this aquatic species. Drupelet fat and sugar content was higher than that for leaf or root tissues in October. This would tend to confirm why drupelets are so eagerly sought after by staging and migrating waterfowl. Trace metal (Fe and Mn) contents in leaf and root tissues accumulated over the season and were very high by fall. However, water and sediment concentrations appear normal. It should be determined whether the trace metal concentrations observed are of natural or anthropogenic origin. Future research should develop a greater understanding of heavy metal accumulation in this and other key Great Basin aquatic plant species.

TABLE 6. Forage quality, mineral and trace element concentration of *P. pectinatus* root tissue (root, rhizome, and turions) averaged over five months. Forage quality constituents and mineral content expressed as % and ppm dry weight \pm S.E., $n > 3$.

Protein	ADF	Fat	TNC ^a	
----- (% dry wt.) -----				
13.0 \pm 1.0	nd ^b	10.9 \pm 3.0	11.9 \pm 1.3	
----- (% dry wt.) -----				
N	P	K	Ca	Mg
2.1 \pm 0.2	0.4 \pm 0.1	2.9 \pm 0.2	1.5 \pm 0.2	0.3 \pm 0.1
----- (ppm dry wt.) -----				
Zn	Fe	Mn	Cu	
167 \pm 25	7166 \pm 1438	2051 \pm 570	14.8 \pm 3.3	

^aTotal nonstructural carbohydrate (TNC), a measure of sugars

^bNot determined

ACKNOWLEDGMENTS

Funding and materials for this study were provided by the Department of Botany and Range Science at Brigham Young University and the Utah Chapter of the Wildlife Society.

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Received 31 May 1994

Accepted 3 January 1995